Detection of Aerosol-Cloud Interactions in Shallow Cumulus during LASSO

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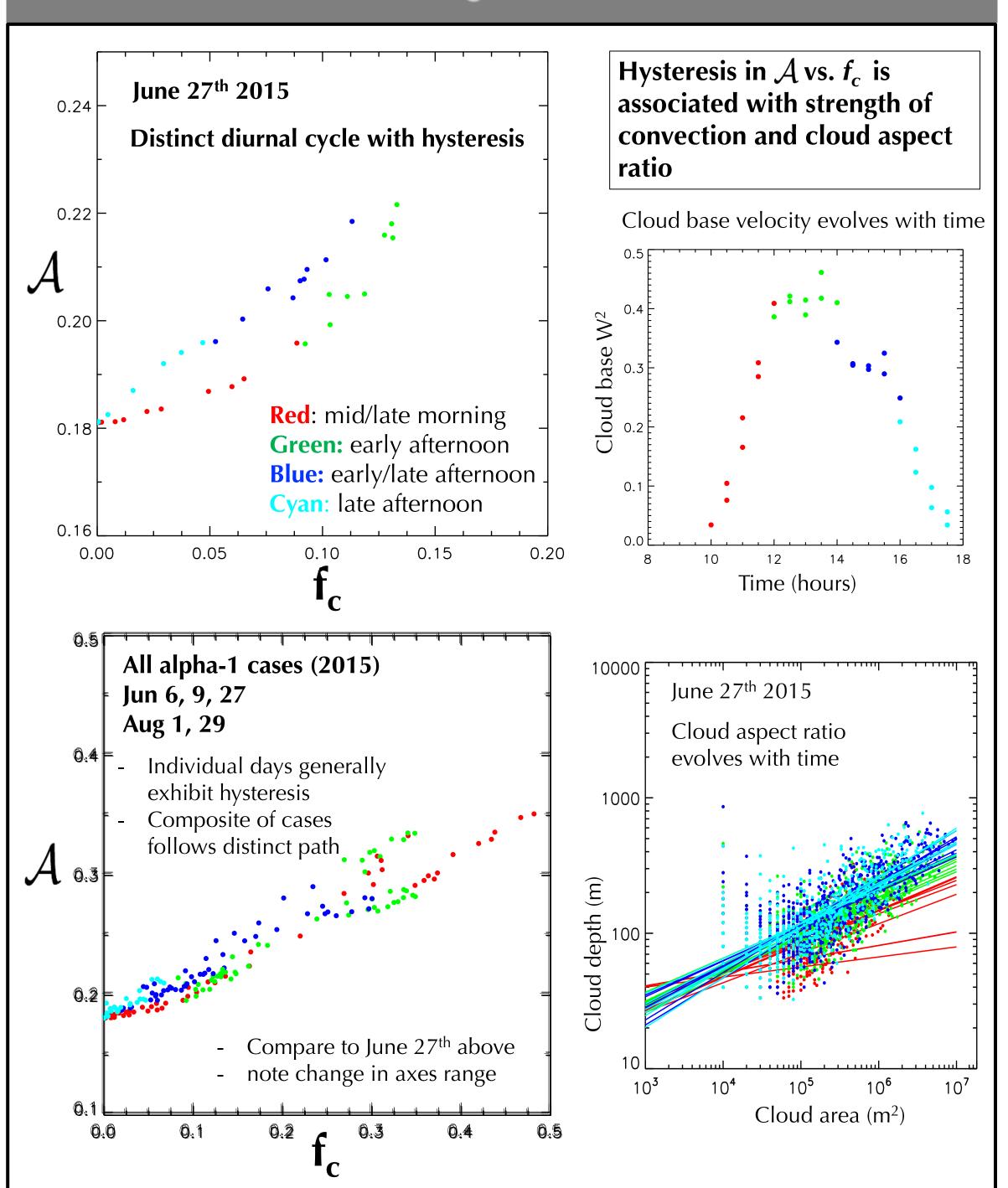
Background and Motivation

Aerosol influences on shallow cumulus:

- hard to quantify with observations
- hard to resolve in climate models

Here we use LES ARM Symbiotic Simulation and Observation (LASSO) model output to evaluate the effect of aerosol on the brightness of clouds at ARM's SGP site

Scene Albedo vs f_c: fixed aerosol



Theoretical considerations

Cloud optical depth: τ_c

Adiabatic clouds: $au_c \propto N^{1/3} H^{5/3}$

 τ_c is 5x more sensitive to H than to N(relatively)

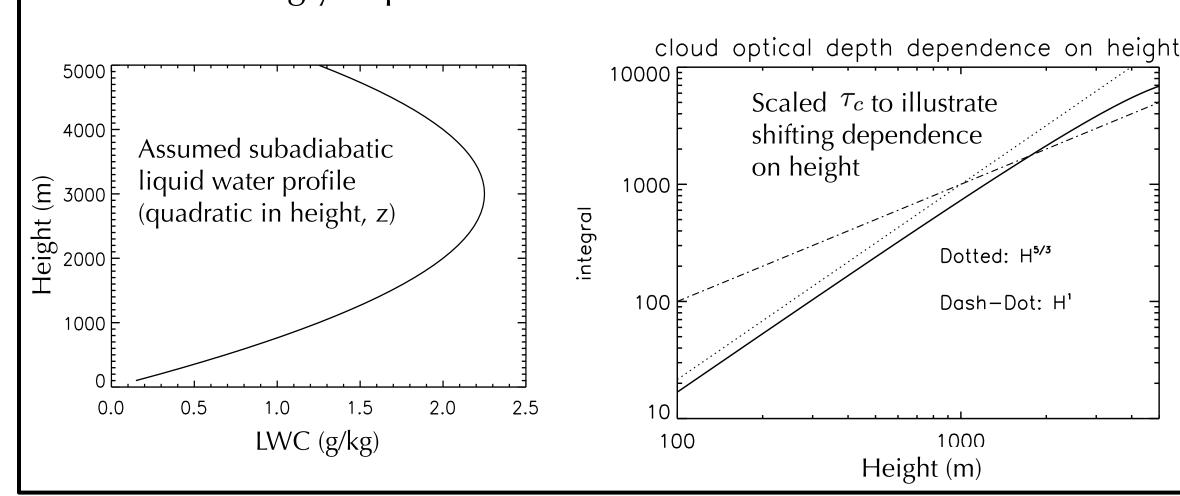
Subadiabatic clouds:

$$\tau_c = CN^{1/3} \int (-pz^2 + qz)^{2/3} dz$$

$$= CN^{1/3} \left[\frac{0.6z(qz(1 - pz/q))^{2/3} {}_2F_1(-2/3, 5/3; 8/3; pz/q)}{(1 - pz/q)^{2/3}} \right]$$

(Feingold et al. 2017)

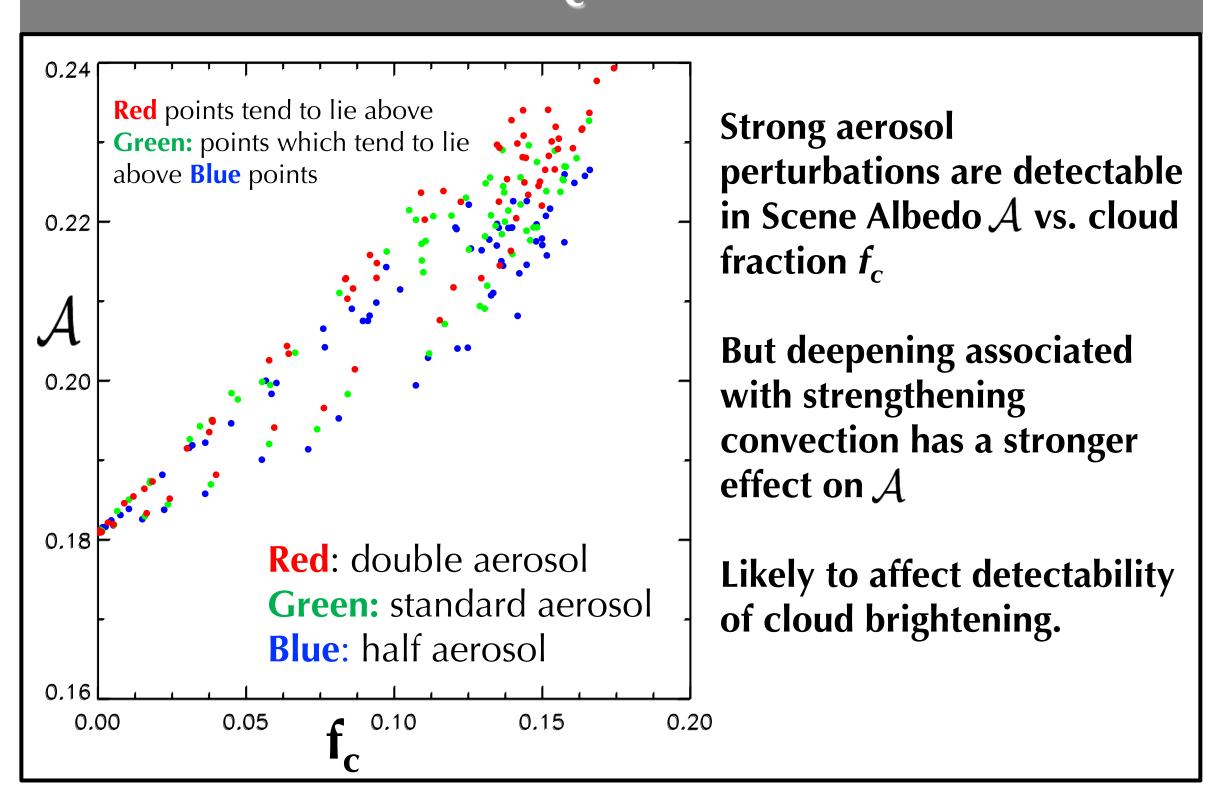
 τ_c dependence shifts from $H^{5/3}$ to H in the example below. Still more strongly dependent on H than N.



References:

Feingold, G., J. Balsells, F. Glassmeier, T. Yamaguchi, J. Kazil, and A. McComiskey, 2017: Analysis of Albedo vs. Cloud Fraction Relationships using Heuristic models and Large Eddy Simulation. J. Geophys. Res., 122, doi:10.1002/2017JD026467. Sena, E. T., A. McComiskey, and G. Feingold, 2016: A long-term study of aerosol-cloud interactions and their radiative effect at the Southern Great Plains using ground- based measurements. Atmos. Chem. Phys., 16, 11301-11318, doi:10.5194/acp-16-11301-2016.

Scene Albedo vs f_c: variable aerosol



Key Points

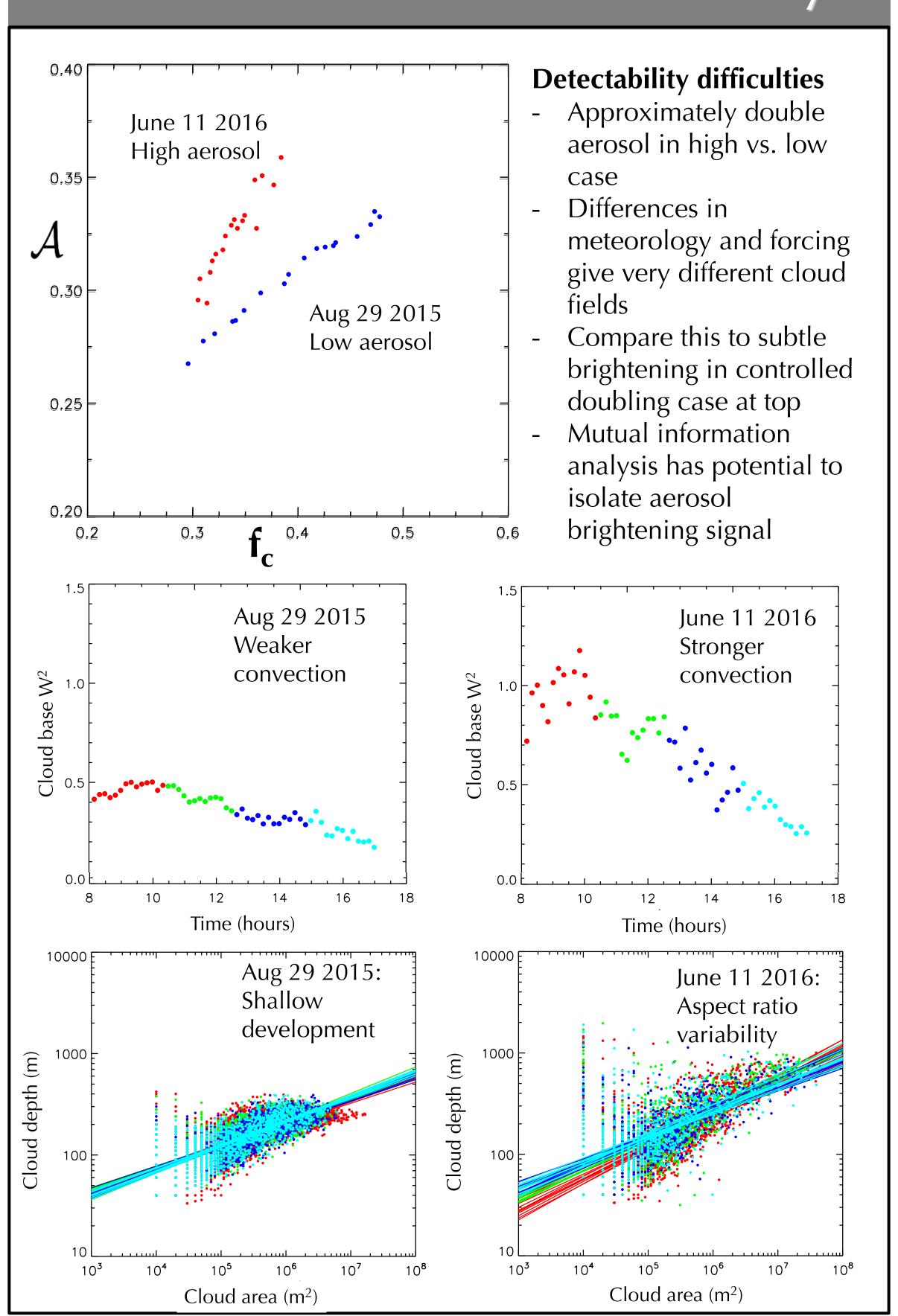
Scene Albedo A vs. Cloud Fraction f_c relationships:

- Useful way to detect aerosol related cloud brightening
- Exhibit diurnal cycle hysteresis related to cloud aspect ratio (depth vs. area)
- Detectability of aerosol effects studied with ad hoc and observed perturbations (derived from CCN spectra)

Aerosol/meteorology co-variability analysis for 14 years of **ARM data at SGP:**

Shannon mutual information is applied to identify and quantify meteorological states affecting detectability

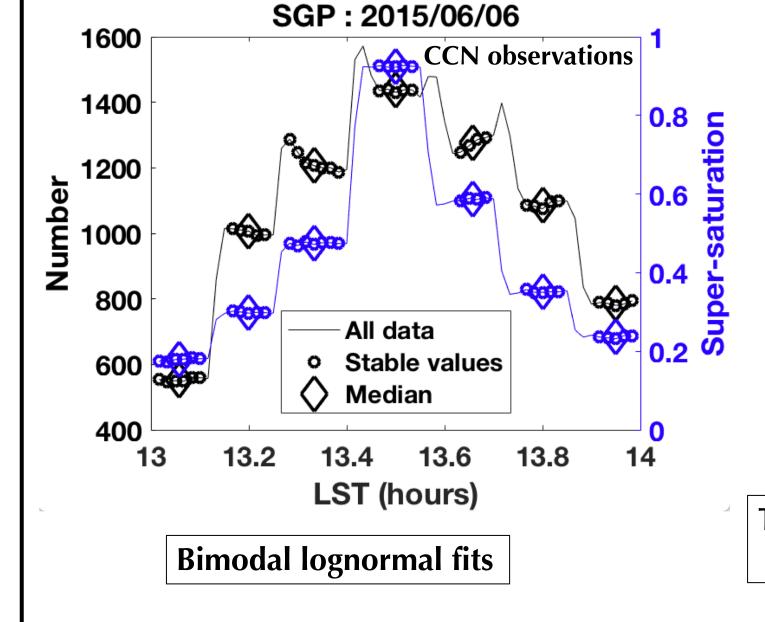
LASSO cases with aerosol variability



Observed aerosol input to model

Aerosol variability

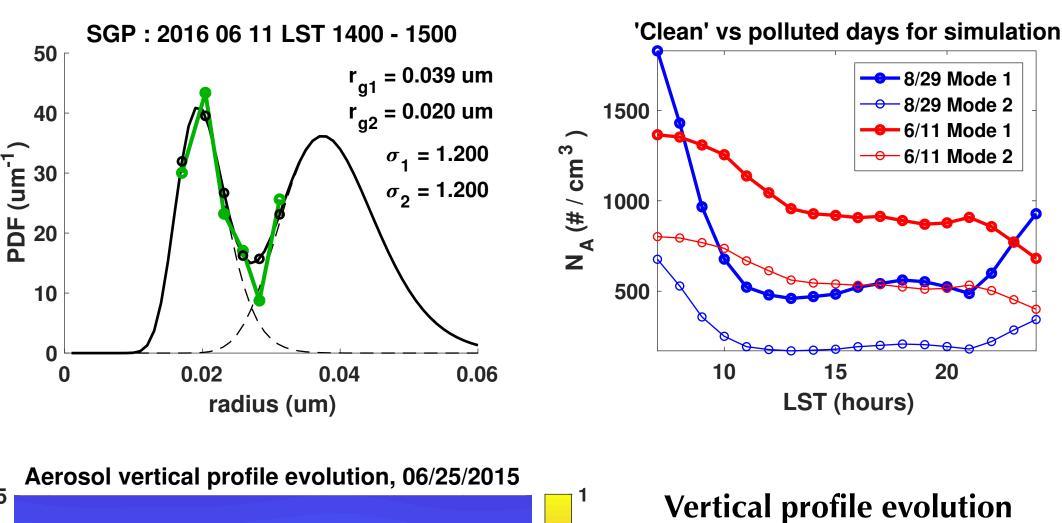
- Based on observed CCN spectra
- Microphysics scheme altered to allow temporal and spatial variability



Method

- Fit bimodal lognormal to CCN spectra
- Fix the size and breadth parameters (r_o and σ)
- Partition the time varying number concentration to each mode

Time-dependent number concentrations



Time (LST)

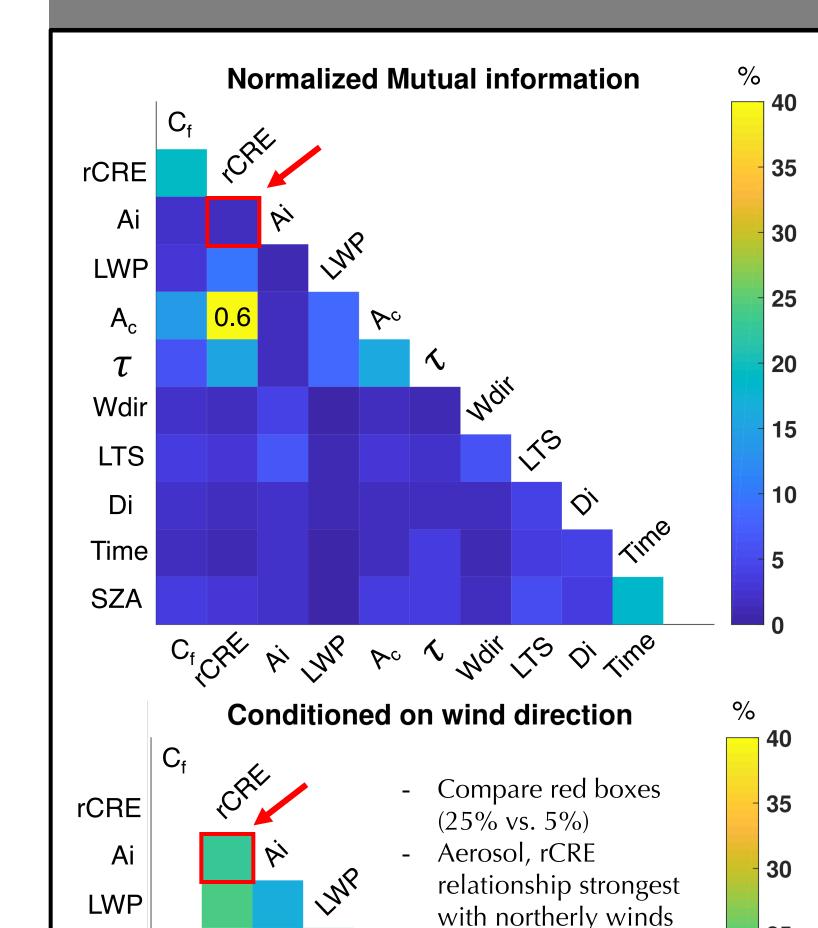
tracer evolves through

advection and diffusion

- Assume an initial tracer

- Scale the aerosol number concentrations with the tracer
- Black line indicates cloud base and cloud top

Aerosol-Radiation Mutual Information



Time

SZA

2016 1997-2010 at SGP

Dataset from Sena et al

- Non-precip. stratocumulus
- Shared "Shannon entropy" Similar to correlation
- coefficient Advantage: Does not require assuming functional

form of co-variability

Shows very weak indirect effect of aerosol index (Ai) on cloud radiative effect (rCRE) (5%; red box)

Conditional mutual information

Shows where co-variability with 3rd variable is hiding true strength of relationship

Advantage

- Can identify which meteorological variables have most interesting covariability with aerosolcloud interactions:
- Wind direction (Wdir), lower tropospheric stability (LTS) identified for further investigation
- Result Detectability of indirect effect (mutual information between rCRE and Ai) greatly increases when conditioning on wind-direction (25%; red box)